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An Electronic Flash Lamp System to Replace the Traditional, Explosively – Driven Light Source

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AN ELECTRONIC FLASH LAMP SYSTEM TO REPLACE THE TRADITIONAL, EXPLOSIVELY - DRIVEN LIGHT SOURCE

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ABSTRACT

Electronic flash lamps are being developed at the Lawrence Livermore National Laboratory (LLNL). These lamps are intended to replace the traditional explosively driven Argon-gas filled light sources (Argon candles) that are currently used to provide illumination for high speed rotating mirror-framing cameras. At Livermore, we are developing an electronic flash lamp system that can match or exceed the light output of a traditional Argon candle. These systems utilize a Plasma Arc Lamp[1,2] developed by PRISM Science Inc of Chatham, MA, USA.

In the past, high-speed photography requiring explosively driven light sources were a one-time-only event that destroyed fixtures and optical alignment. The electronic flash lamp system, utilizing the Plasma Arc Lamp, will replace the explosively driven lighting systems and provide the capability to dry run experimental setups and repeat tests without damage to the experimental set-up. The electronic flash lamp system eliminates the problem of collateral damage to the experiment and does not add to the overall amount of explosives needed for a single test. Since the Pulsed-Power driver is remotely located, only the flash lamp itself is destroyed when the explosive shot is fired. The flexible geometry of this light source also enables the user to create complex light patterns as well as photograph very large areas with a single lighting system.

This electronic flash lamp system will provide an extremely bright, stable, and repeatable light source for rotating-mirror framing cameras operating at one million frames per second, using both black & white or color films. The design of the Pulsed-Power driver and the flash lamp, along with experimental data and results will be discussed.

KEYWORD LIST

Flash Lamps, Light Sources, Rotating Mirror Cameras, Explosives, Illumination, High-Speed Photography.

INTRODUCTION

At LLNL we are in the process of transitioning from explosive lighting systems to electrically driven light sources. The reasons for this transition are that we have recently activated a Contained Firing Facility (CFF), which has a limited capacity to contain a detonation. The use of electrically driven light sources greatly reduces the explosive burden placed on the facility. Two years ago, we picked the Plasma Arc Lamp (PAL) for evaluation and characterization. The lamp has several advantages over other types of discharge lamps. Most importantly, the lamp has a light output that is on par with an explosive candle (1.6 Giga-Lumen), and secondly, the lamp is substantially less expensive than the alternatives. Adapting the lamp to our existing flashlamp system was not without its difficulties, as the electrical characteristics of the PAL differ significantly from the capillary lamps that we have been using to date. Unlike a capillary lamp, whose impedance stabilizes quickly when the plasma channel grows to fill the bore, the impedance of the PAL continues to change as a function of time, since the arc is free to expand. In the time frame of our tests, we were never able to achieve a steady-state condition. The PAL's impedance also varies with charge voltage, gas pressure, arc length, and ground-plane width, and it's intrinsic impedance is so low it is almost a short-circuit. We found it necessary to connect

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lamps in series, and to adjust the lamp parameters to attain reasonable impedance. A matching low impedance power source also had to be constructed. We also found that initiating and maintaining the breakdown in a PAL required additional circuitry that is not required by a standard flashlamp.

In this paper we summarize the results of two years of research directed towards adapting the PAL lamp to our flash-lamp banks. Much of our time was spent characterizing the dynamic impedance characteristics of the lamps as a function of several parameters, and characterizing and measuring the light output against our standard candle.

MECHANICAL DESIGN

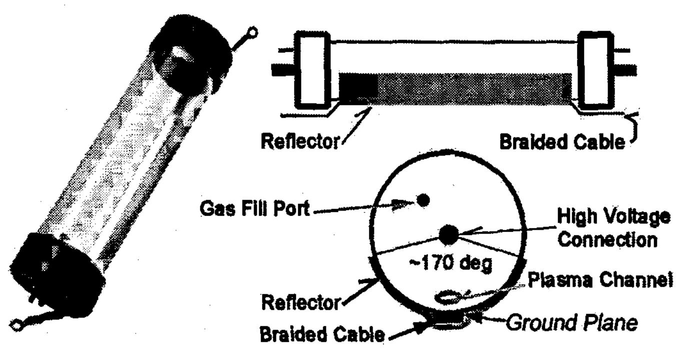

Fig. 1: Lamp Construction

The basic mechanical design for the PAL consists of a 7.6 cm diameter plastic tube, 30 cm long, with injection-molded end-caps. A ground-plane is attached to the outside of the tube. This ground-plane enables the formation of the plasma channel inside the tube. Braided cable runs on top of, and electrically attaches the ground-plane of each lamp to the next lamp. A reflector is attached to the outside of the tube to increase and focus light in the forward direction. The design of the reflector enables us to control the light pattern on the target. Gas fill ports and high-voltage connections are found on the end-caps at both ends of the lamps, enabling series lamp configurations.

LAMP CHARACTERIZATION

The electrical characteristics of the PAL differ so significantly from the capillary lamps that we have customarily used, that we found it necessary to construct a lamp test stand for testing and characterization. Current and voltage probes were attached to lamps within the test stand, as well as pressure sensors to monitor the gas pressure within the tube. The fill gas in all cases was Xenon. The lamp output of the lamps was measured with a vacuum photodiode aimed at a KODAK 18% gray card. Each shot was monitored on a digital oscilloscope and logged into a computer for digital post-processing in IGOR. The current and voltage data were used to develop impedance curves as a function of time.

Once the test stand was operational, we started by comparing the behavior of a standard PAL configuration of three lamps in series against a capillary lamp using our standard 2-ohm Pulse Forming Network (PFN). This is illustrated in Fig. 2. Note that the impedance curve of the capillary lamp, a FT-623, stabilizes rapidly after the establishment of the arc at 2-ohms, while the impedance of the PAL starts higher, crosses over, and then continues to fall over the duration of the discharge. We then adjusted one parameter at a time, holding the others fixed, and recording the effects. Our efforts were concentrated on parameter changes that would drive the lamp impedance up, as the low intrinsic impedance of the PAL made it difficult to design a PFN that could deliver the required current.

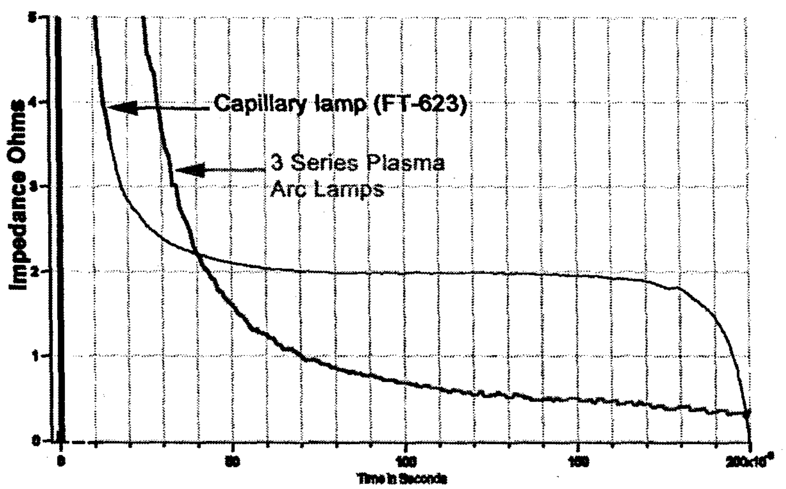

Figure 2, Impedance capillary vs. Plasma Arc Lamp

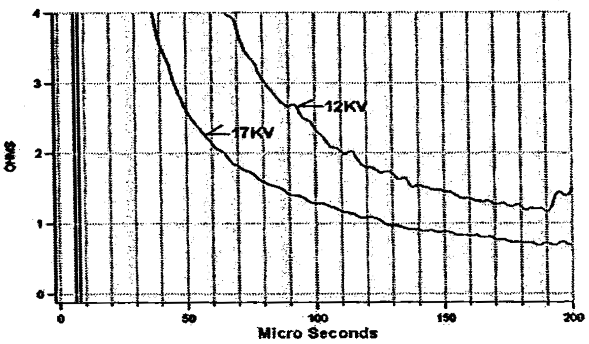

Fig. 3 Impedance vs. Voltage

The data used to generate the curves in Fig. 3, were used to determine the dynamic voltage-current relationship of the PAL. The data is regenerated here as a voltage-impedance plot, as an aid to developing our final PFN design. The gas pressure in this, and all of the tests where this was the fixed parameter, was 69 kPa. All parameters measured after this, were taken at the standard 17 kV operating voltage of the bank.

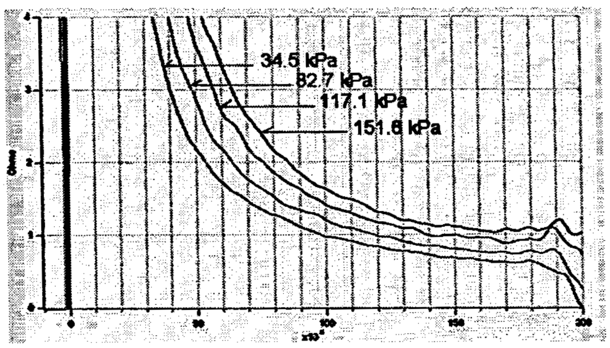

Fig. 4 Impedance vs. Pressure

In Fig. 4, the impedance shift is plotted as a function of pressure. Pressures in the range of 117 kPa to 152 kPa gave us an impedance near one-ohm, which we later chose for our bank impedance. Large gains in light output were seen with increasing pressure up to 138 kPa, partially due to the better impedance match between the lamp and the PFN. Additional triggering circuitry had to be added at the higher pressures to trigger the lamps reliably.

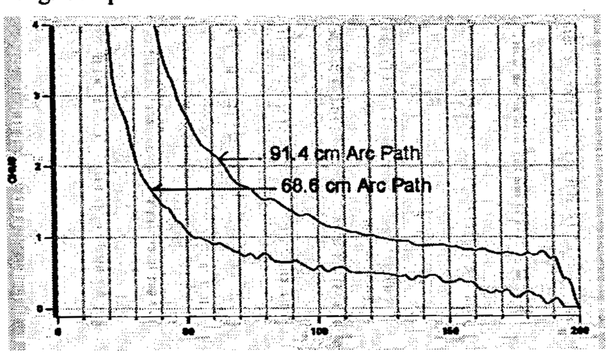

Fig. 5 Impedance vs. Arc Path

The arc resistance increased with increasing arc length as expected. The impedances for two lamps (68.6 cm) and three lamps (91.4 cm) in series are plotted in fig. 5.

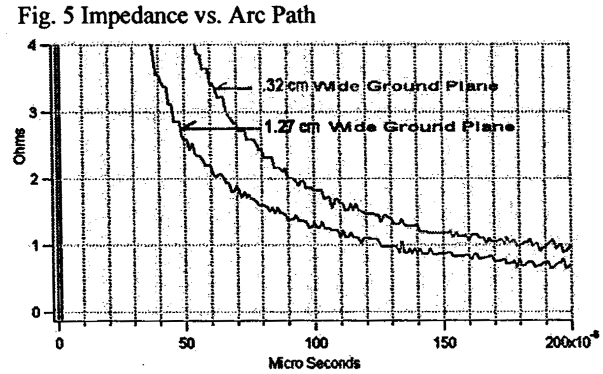

Fig. 6 Impedance vs. Ground Plane Width

Lastly, we changed the width of the ground plane from 1.27 cm to 0.32 cm. The ground plane initiates and guides the plasma channel and has a strong effect on its size. A smaller ground plane initially forms a smaller diameter discharge with higher impedance. The results are shown in fig. 6.

BANK DESIGN

We used our parameterization data to modify the PFN. The impedance of the bank was lowered to 1-ohm, while at the same time, the impedance of the lamps was raised to near an ohm, by increasing the number of lamps, and adjusting the pressure upwards. The bank impedance was also tapered to flatten the output pulse. The resulting output pulse has a falling flattop characteristic, but since photographic response is logarithmic, the exposure appears to be constant during the discharge. The PFN is shown in Fig. 7, and consists of the inductors L1, and L2, and the capacitors, C1, and C2. The ignitron, S1, initiates the trigger sequence, connecting the Initial Breakdown Capacitor (IBC), which is external to the PFN, to the lamps through the triggering circuit resistors, R1, R2, and R3. The trigger transformer, TT, breaks down the lamps, while the IBC continues to supply energy until the PFN can sustain the plasma channel in the lamps. The IBC, the trigger transformer, TT, and the resistors, R1, R2, and R3, were added to assist in triggering the lamps.

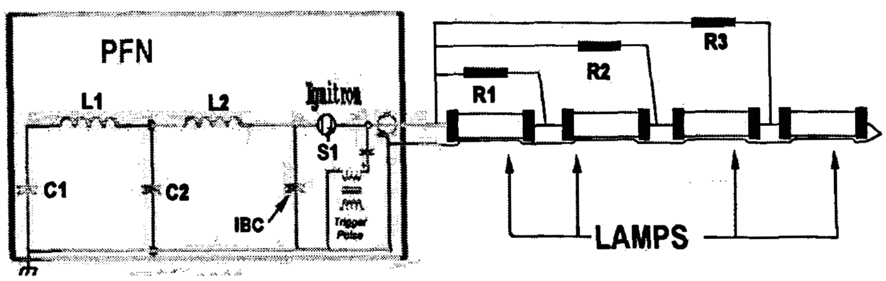

Fig. 7, Schematic of the PFN and Lamp System

LIGHT OUTPUT

Simultaneous photographic and photometric measurements were taken of both a PAL (4, series lamps), and a 15 cm Argon candle. Analysis of fig. 8, photograph, with a rotating-mirror camera set at a 1-µs inter-frame time, shows that the PAL illuminates five times the area, has better color rendition, and a higher light output, than the explosively-driven Argon candle. A PIN diode with a visual band-pass filter, measuring the illuminance of a KODAK 18% gray card was used to compare the light intensity of both sources, fig. 9. The illuminance we have achieved to date is around 2 Gigalux. Power dissipation at this light output is ~670 kilowatts per cm, with 0.91 m total arc length. Increasing the energy in the arc rapidly reaches the point of diminishing returns, as the spectral peak starts to shift strongly into the ultra-violet at 800 kilowatts per cm.

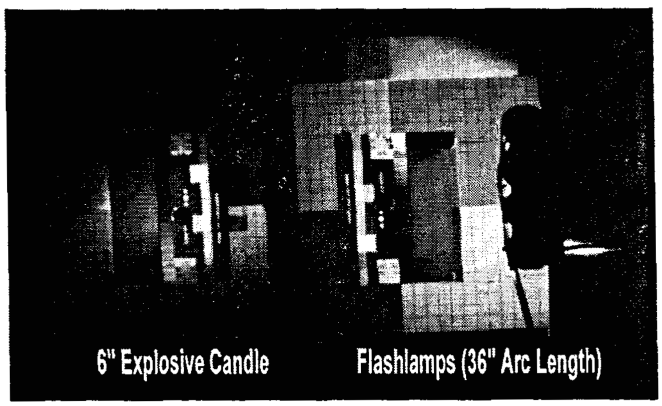

Fig. 8, Photographic Lamp and Candle Comparison Test

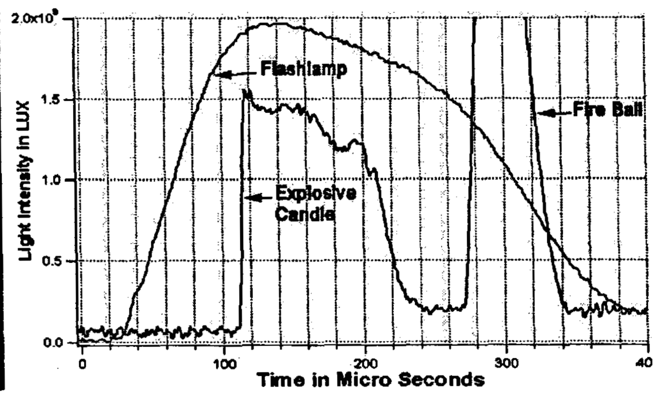

Fig. 9, Photometric comparison of a PAL and an Argon Candle

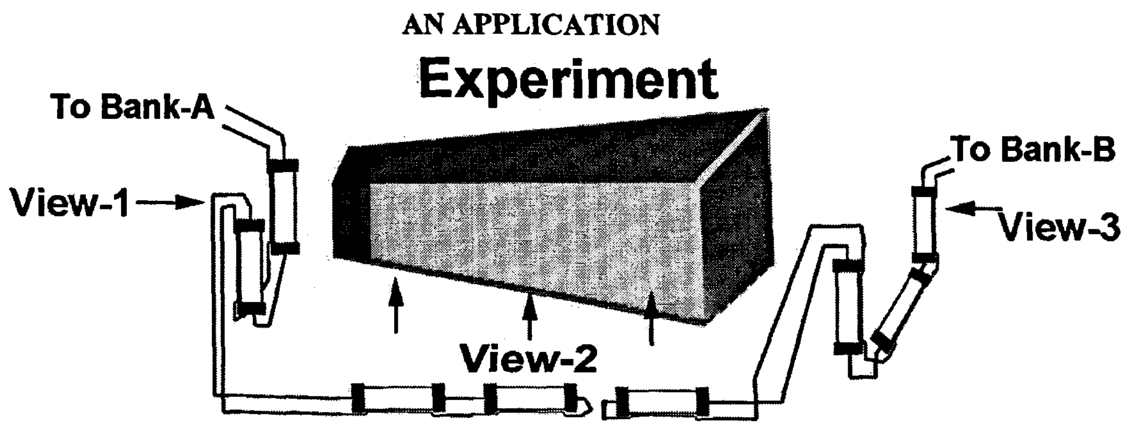

Fig. 10, Experimental set-up, August 2002

The electronic flash lamp system was used on a real experiment in August 2002. The lamps were distributed around the experiment, unlike the configuration in previous illumination tests, in which the lamps were tightly clustered,. In fig. 10, the distribution of lamps and the size of the illuminated area in this experiment is illustrated. Two PFNs drove four lamps each. Two Lamps of Bank-A illuminated the first view, while the remaining two lamps, separated by 76 cm, illuminated two-third's of the second view. Three lamps of Bank-B illuminated the third view, while the fourth lamp, separated by 127 cm, illuminated the remaining third of the second view. The lamps were pressurized with Xenon at 83 kPa, and the banks were charged to 17kV. The flash lamp system replaced 9 Kg of explosives, which would have been required to illuminate the experiment. All three views were evenly exposed with good color saturation. This was the first time Lawrence Livermore National Laboratory applied flash lamps to a full-scale experiment.

CONCLUSIONS

The change to Plasma Arc Lamps has eliminated diagnostic explosives, and given us the ability to dry run illumination systems. The color temperature of the PAL more closely approximates daylight and illuminates an area 5 times larger than a 15 cm. Argon candle. The lamp cluster can be broken up and the segments individually redistributed around the experiment to illuminate multiple views. PALs have increased the amount of explosives that can be added to an experiment without exceeding the mandated explosive weight limits. This technology also aids in waste minimization programs.

The versatility of Plasma Arc Lamps and their ability to outperform explosively driven candles, verify views, and exposure makes them a valuable tool for high-speed photography. The continued development of the electronic flash lamp system is required in order to meet the future programmatic needs of high speed photography at Lawrence Livermore National Laboratory.

ACKNOWLEDGEMENTS

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